LA-UR-19-20325
Approved for public release; distribution is unlimited.

Title: Active Neutron Measurement Techniques

Author(s): Root, Margaret A.

Intended for: Nuclear Safeguards Course

Issued: 2019-01-17

Los Alamos
NATIONAL LABORATORY
EST.1943

Active Neutron Measurement Techniques

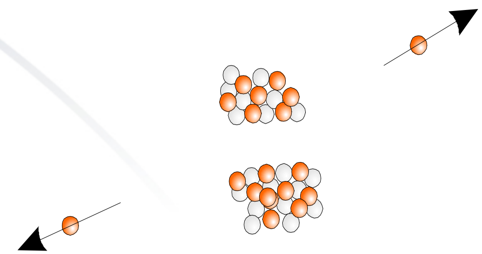
SEE LANL

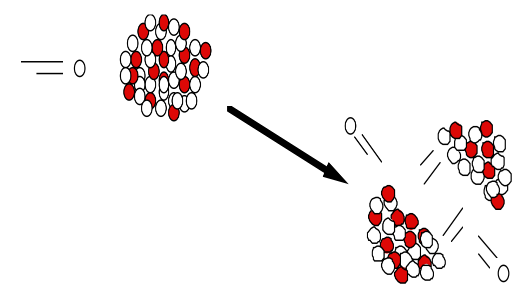
January 23-25
2019

UNCLASSIFIED

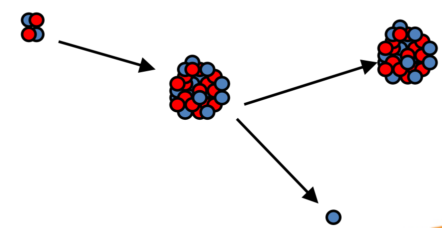
Processes that generate neutrons

- Fission
  - *Spontaneous*
    - Nucleus splits all by itself, randomly
    - ^{238}U, ^{238}Pu, ^{240}Pu, ^{242}Pu, Cm, Cf
  - *Induced*
    - Heavy isotope absorbs neutron, causing it to split → Multiplication
    - ^{235}U, ^{239}Pu, ^{233}U
  - Bursts of 0-8 time-correlated neutrons emitted





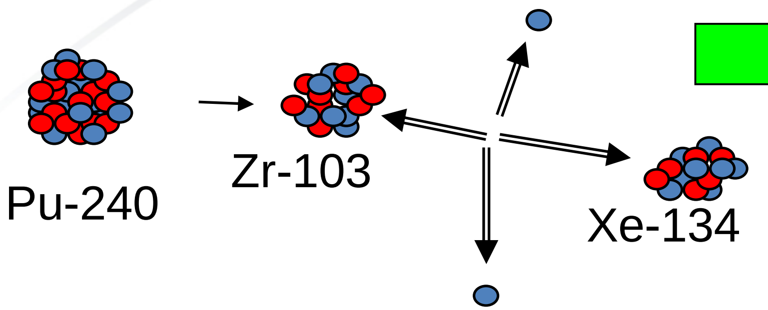
- (α,n) reactions
  - Helium nucleus reacts with light element nucleus, generating a <u>single</u> neutron and a new light element
  - Neutron emission depends on item composition

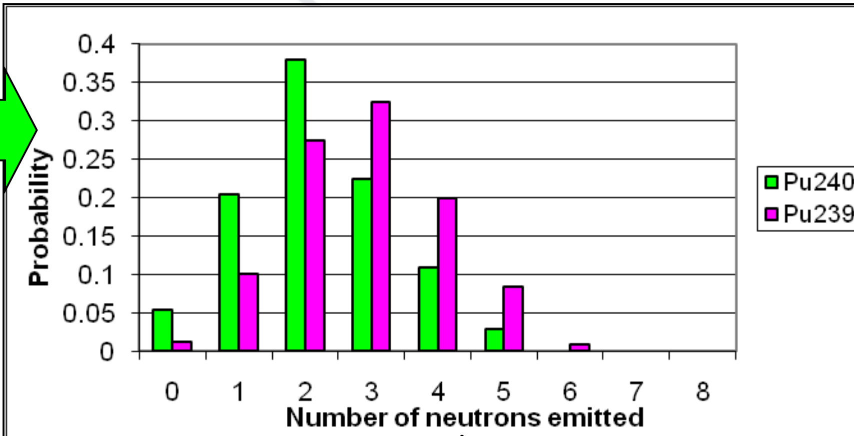


- Less common reactions
  - Cosmic rays, (n,2n), (p,n), (γ,n)

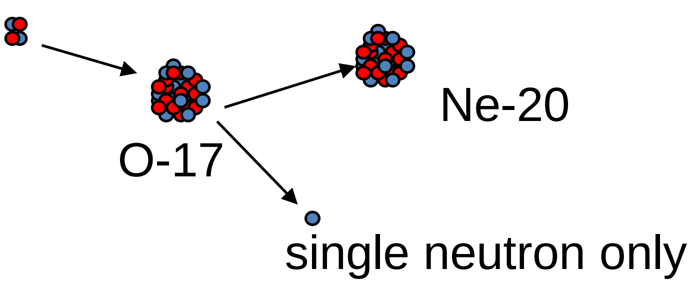
Neutron Signatures

Spontaneous fission

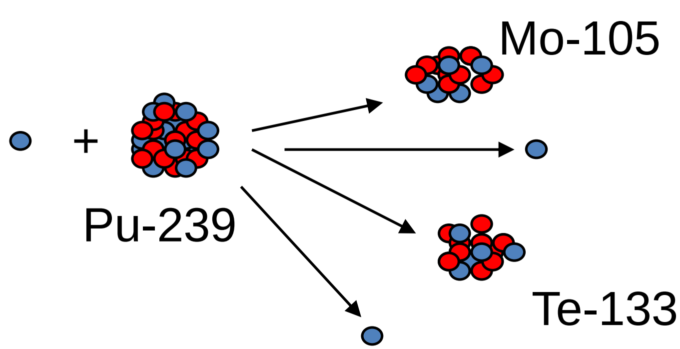




(alpha,n) neutrons



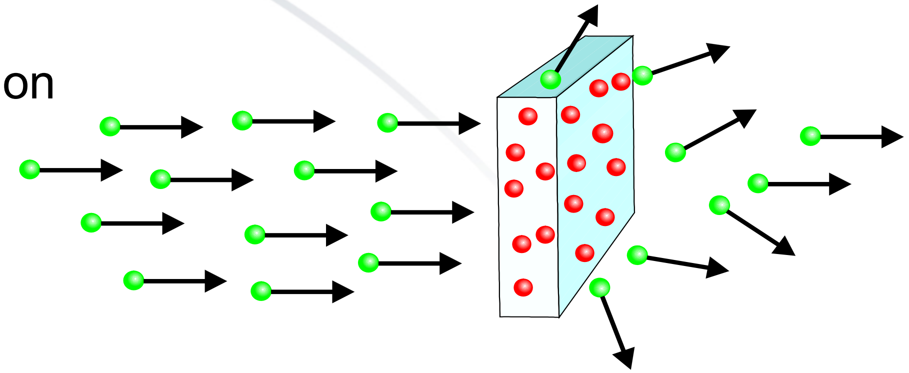
Induced fission



UNCLASSIFIED

Basic neutron interactions

- Scattering
  - Neutron collides with a nucleus, causing neutron's speed and direction to change, but leaving the properties of the nucleus the same as before the interaction



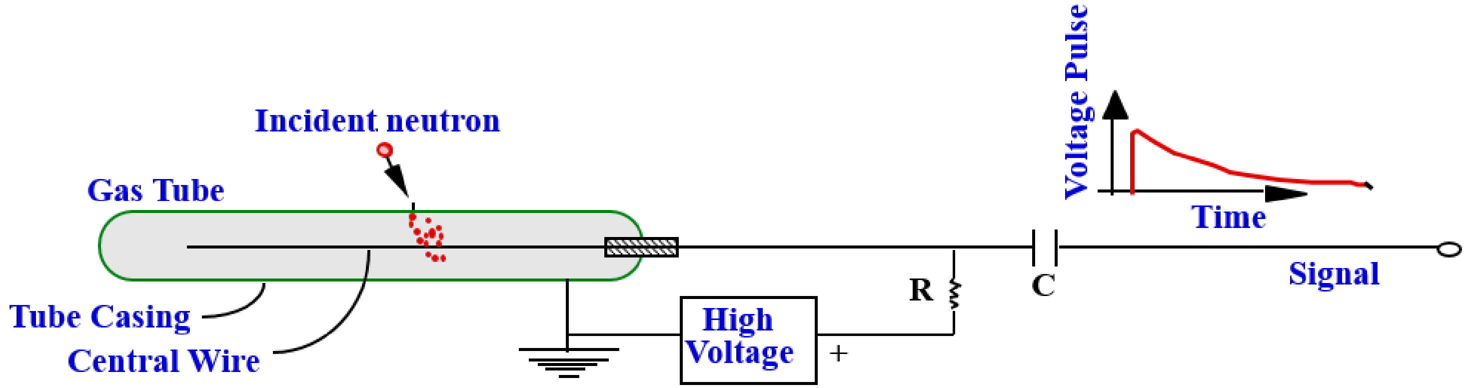
- Moderation
  - Neutron scattering process by which a neutron collides with matter and loses energy
    - i.e. 2 MeV to 0.025 eV
  - Best moderation when neutron collides with nuclei of similar mass
    - e.g. Water, polyethylene, other hydrogenous materials, $m_H \sim m_n$
- Absorption
  - Neutron is absorbed, yielding an excited nucleus, which de-excites through the release of something else, like a proton or a gamma ray
    - e.g. (n,γ), (n,p), and fission reactions.

UNCLASSIFIED

Why measure neutrons?

- Neutron rates are related to the amount of fissionable material. (Pu, U, etc. – what we need to safeguard)
- Highly penetrating.
  - Low rate of interaction with matter.
  - Can measure entire volume of item.
  - Can measure large-volume items. Gamma rays are limited (typically) to smaller items. ("Skin thickness")
- Insensitive to interference by other gamma-emitting radionuclides (unless a (γ,n) source)

Neutron detector design



- Uses ^{3}He tubes embedded in moderating material (polyethylene).
  - Fission neutrons emitted at MeV energies
  - ^{3}He tubes are most sensitive to low energy “thermal” neutrons E_{ave} ~ .025eV
- Releases charge which is collected by gas tube.
- Detectors produce a distribution of electrical pulses.
- Electronics amplify the pulses, sets threshold, and converts pulses above threshold to digital pulses.

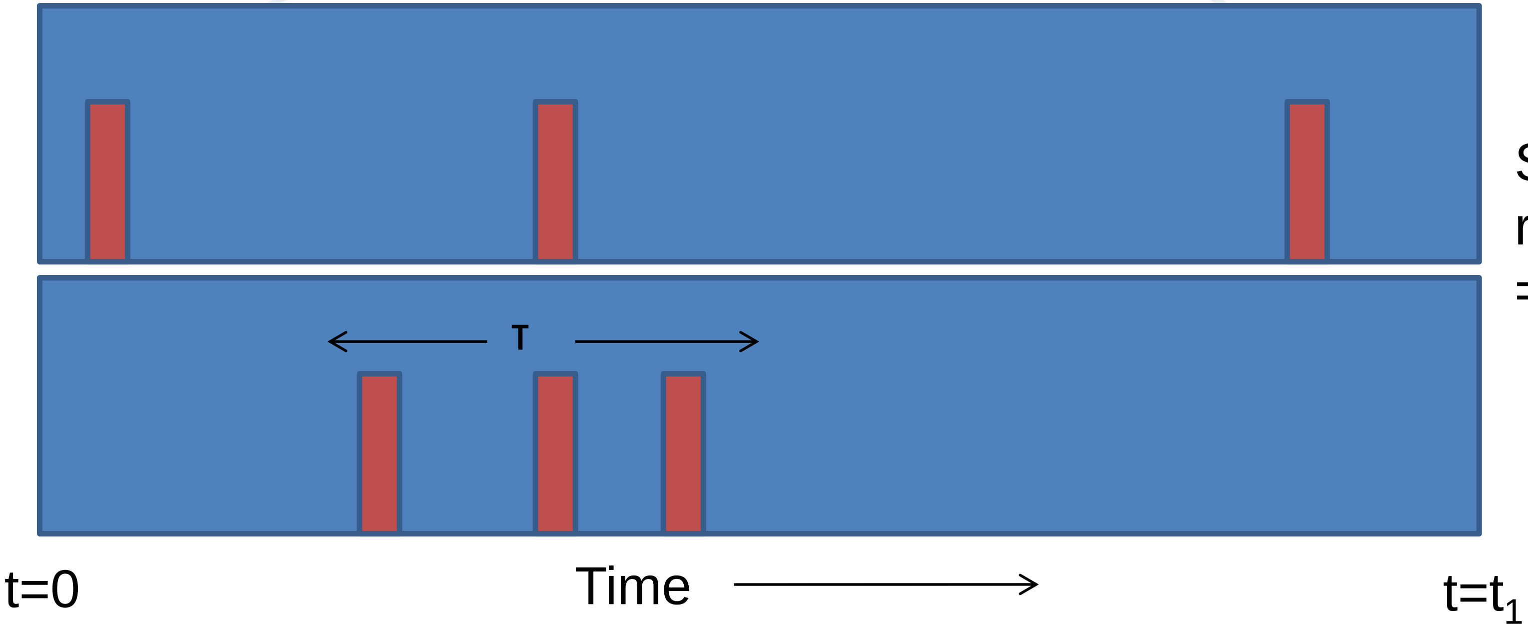
UNCLASSIFIED

Instrument Choices

- Passive Assay
  - Used for spontaneous fission
  - Count neutrons produced by sample.
  - Plutonium Assay: $^{240}Pu_{eff}$
  - ^{239}Pu inferred from isotopics.
  - High Level Neutron Coincidence Counter (requires representative standards)
  - Neutron Multiplicity Counter (applicable to wide range of material)
- Active Assay
  - Used for induced fission when there is no (small) spontaneous fission
  - ^{239}Pu, ^{235}U
  - Count neutrons induced by source.
  - Active Well Coincidence Counter
  - Uranium Neutron Coincidence Collar

Correlated Pulses

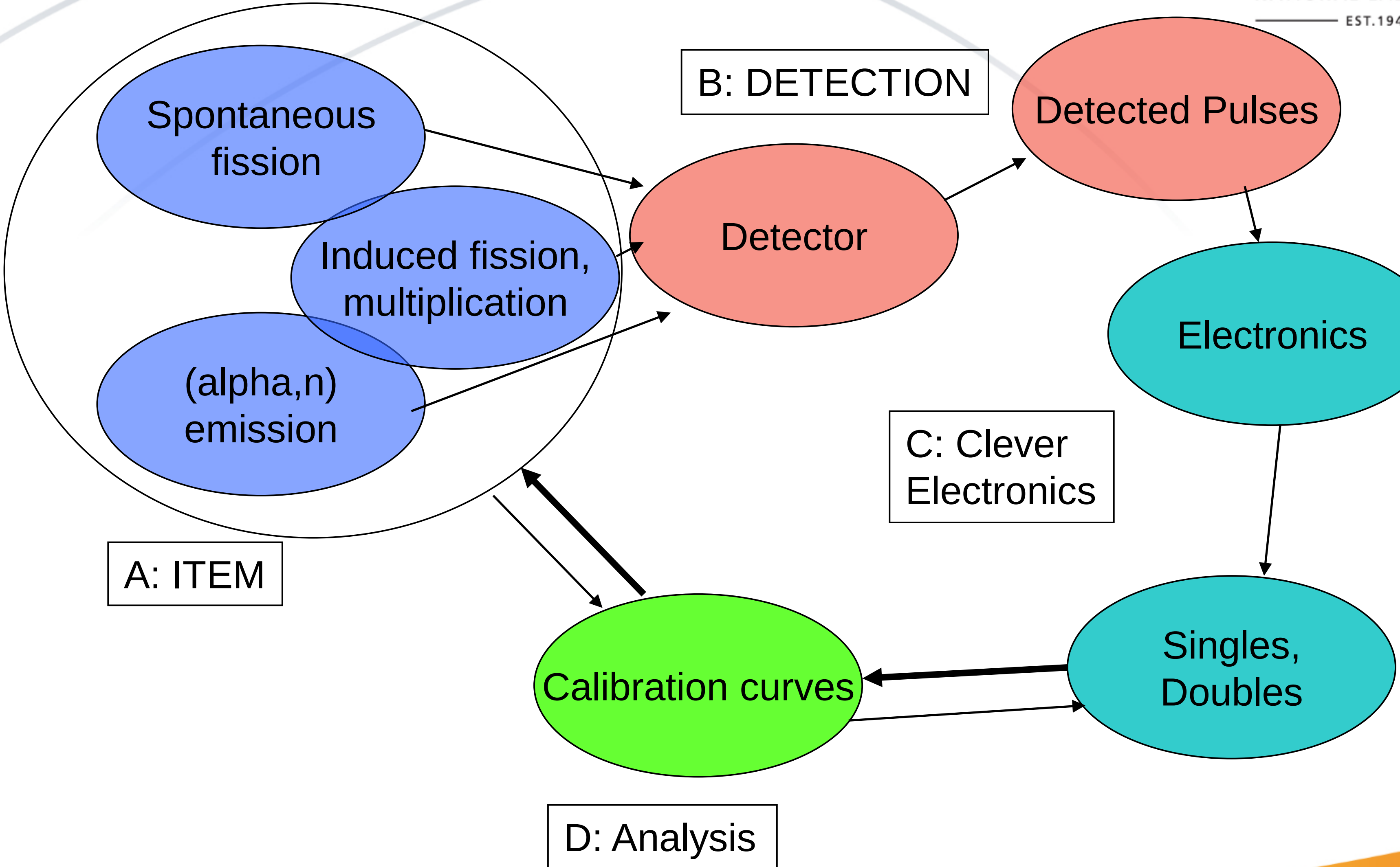
Two Pulse streams:



Same count rate,
$= 3/t_1$

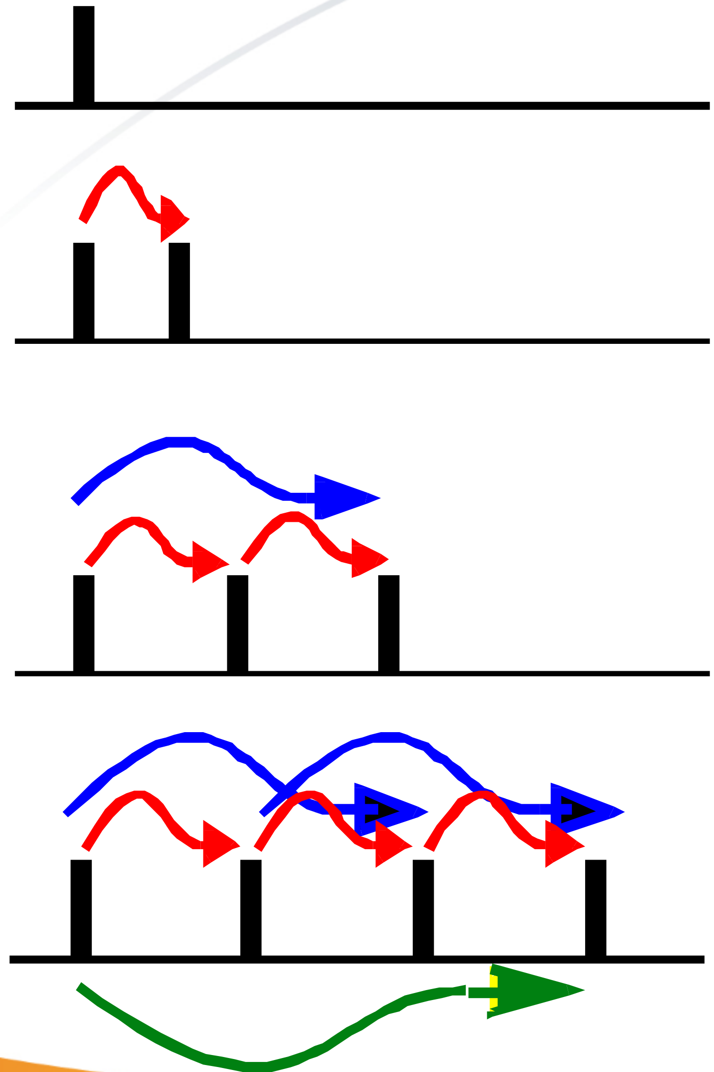
- Pulses from one fission event are clustered together in time.
- Pulses from unrelated events are distributed randomly in time
- We want a device to distinguish between these two different pulse steams

Coincidence counting process



UNCLASSIFIED

Neutron coincidence counting



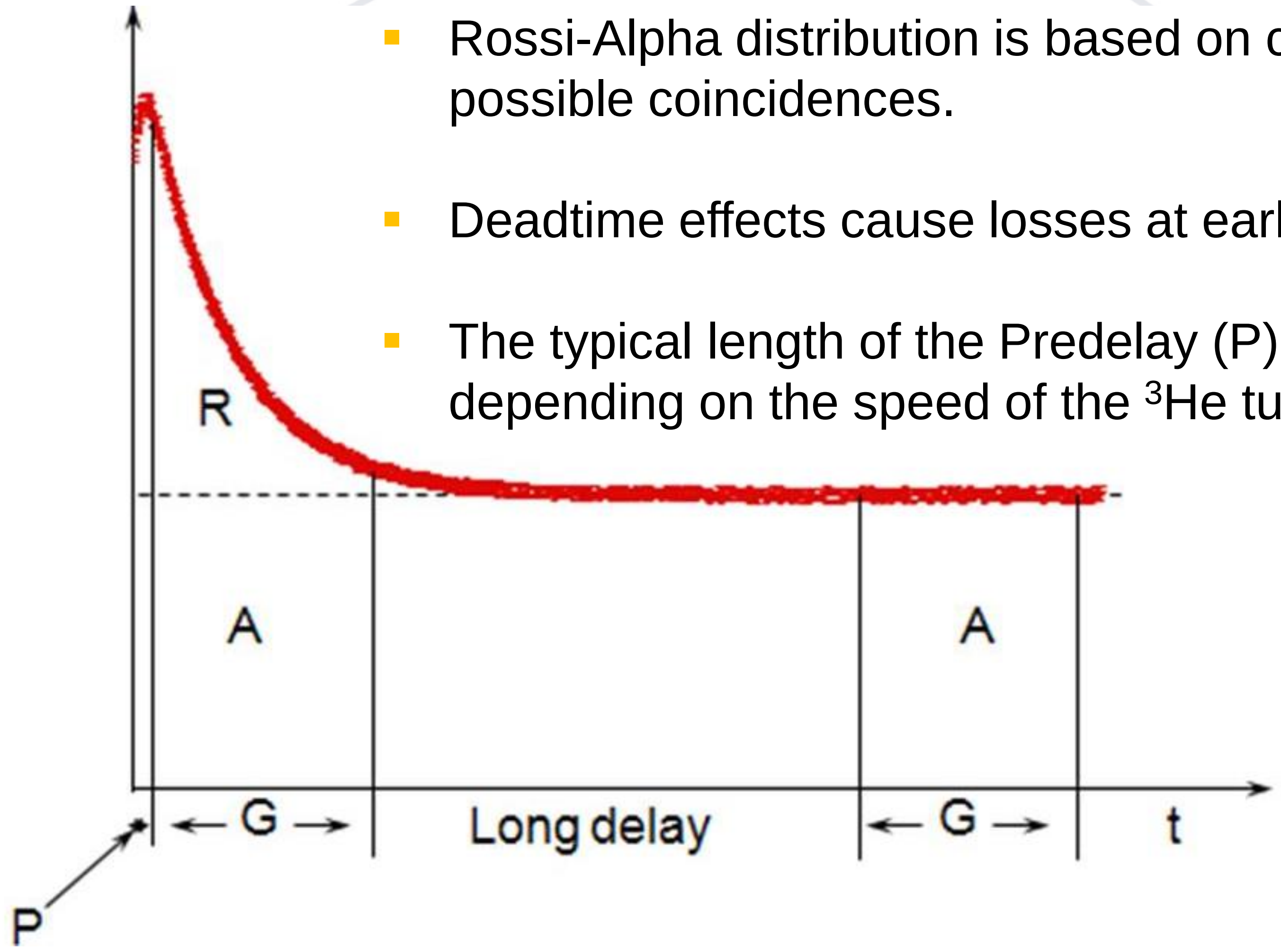
1 Pulse, 0 Coincidences

2 Pulses, 1 Coincidence

3 Pulses, 3 Coincidences

4 Pulses, 6 Coincidences

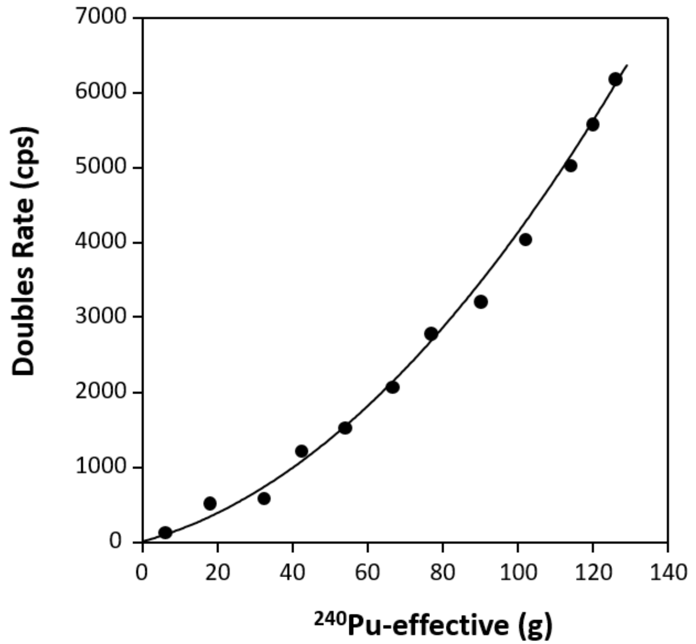
Rossi-Alpha Distribution



- Rossi-Alpha distribution is based on counting all possible coincidences.
- Deadtime effects cause losses at early times.
- The typical length of the Predelay (P) is 2 to 4.5 ms depending on the speed of the ^{3}He tube and amplifier.

Calibration Curve Method

Calibration Curve Method

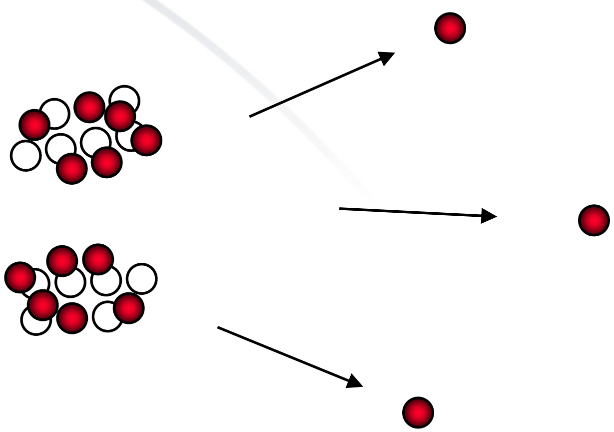


- Need representative items for each item type and careful calibration measurements.

Active Neutron Coincidence Counting

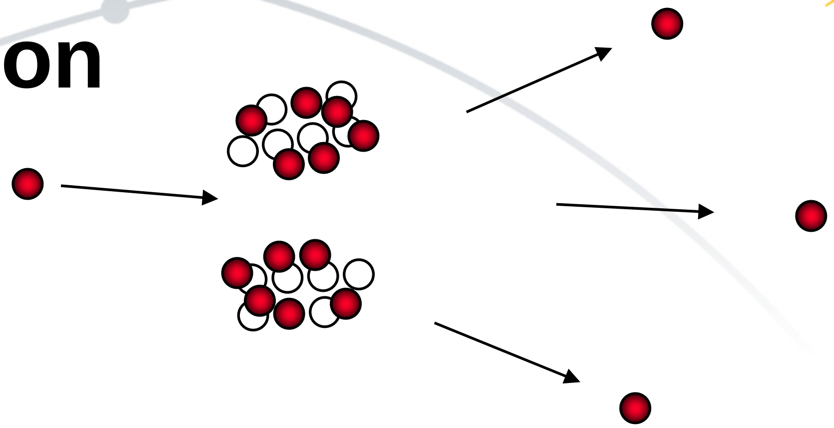
Spontaneous Fission

Nuclide	Specific Intensity [n/(g.s)]
^{234}U	0.005
^{235}U	0.0003
^{236}U	0.0055
^{238}U	*0.0136*
^{238}Pu	2590.
^{239}Pu	0.022
^{240}Pu	1020.
^{241}Pu	~0.05
^{242}Pu	1720.
^{241}Am	1.18
^{252}Cf	2.34E+12



Uranium spontaneous fission emission rate is very small and is generally not useful for NDA except for large quantities of ^{238}U

Induced Fission

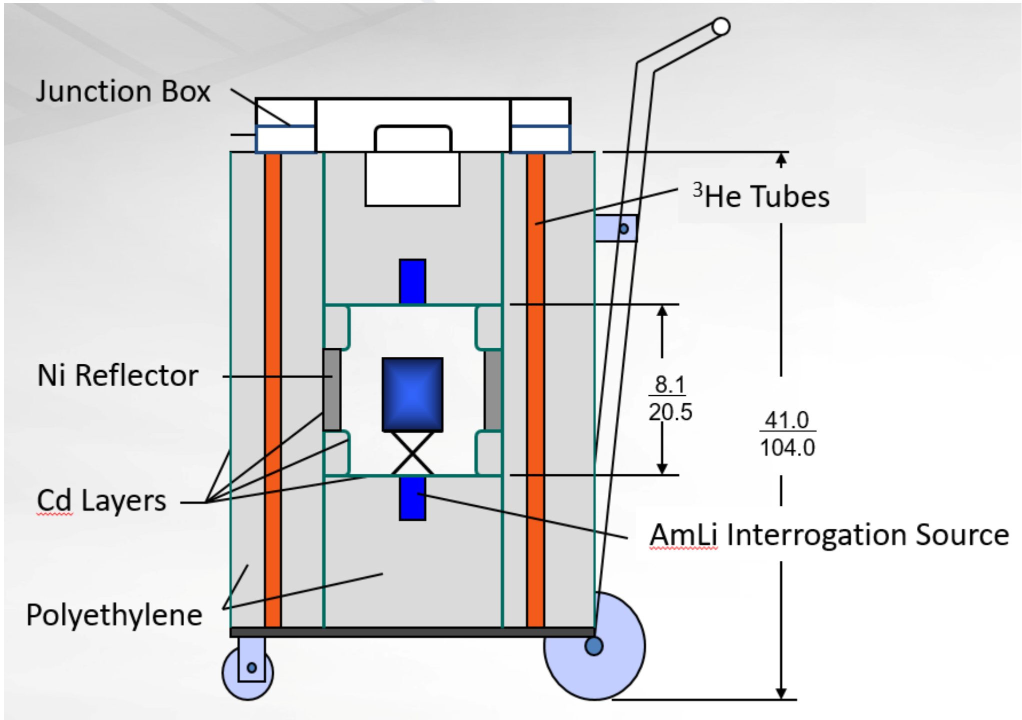


- Induced fission is the primary method for uranium assay.
- Uses AmLi interrogation sources because they produce only random neutrons and have a low energy spectrum that will only induce fission in ^{235}U
- Neutron emission occurs in bursts (0-8)
- The coincidence rate is related to the ^{235}U mass.
- Coincidence rate is dependent on item properties: geometry, item composition, density.

UNCLASSIFIED

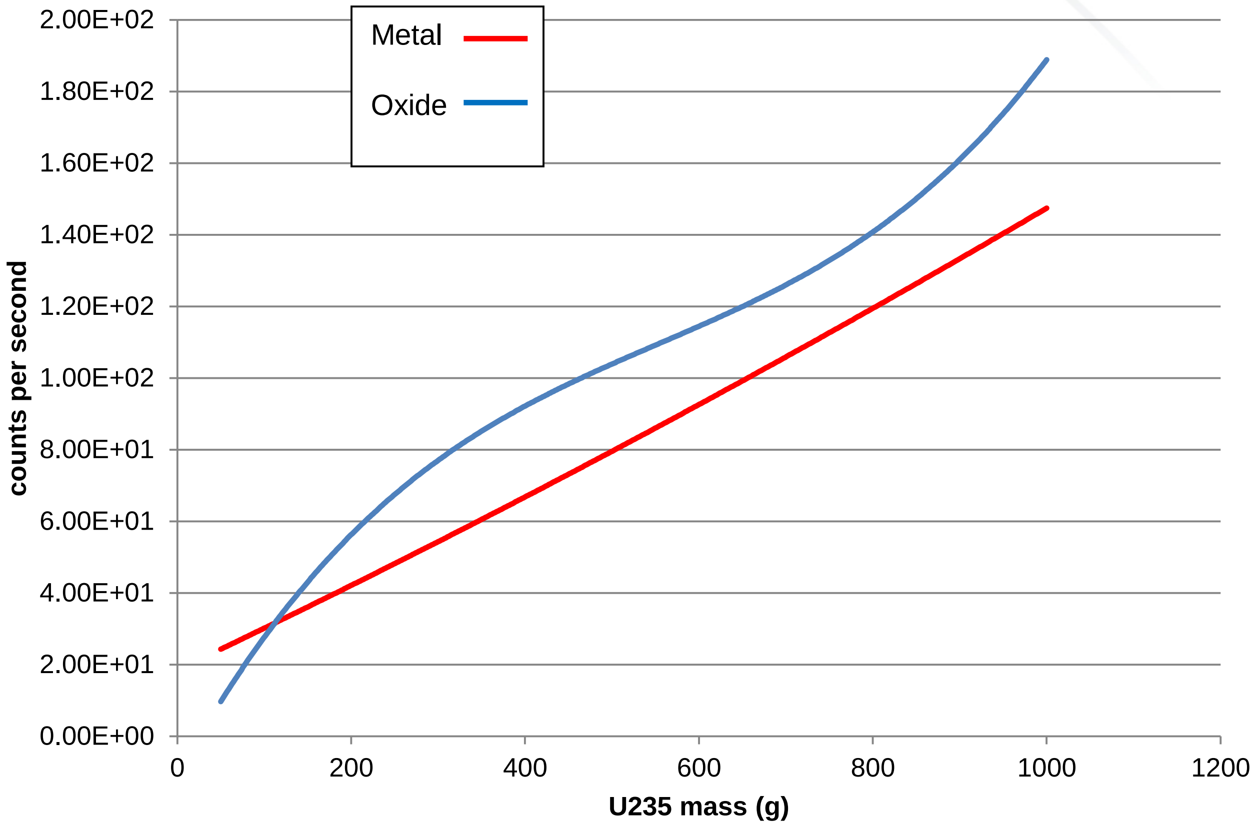
Active Well Coincidence Counter (AWCC)

- Designed in 1984 (Mod II)
- Assay range of few gram to several kg of ^{235}U
- Can be used in passive or active modes
- Portable
- Good efficiency – 42 ^{3}He tubes
- Uses two AmLi sources for uniform interrogation
- Several cavity configurations for optimization of performance



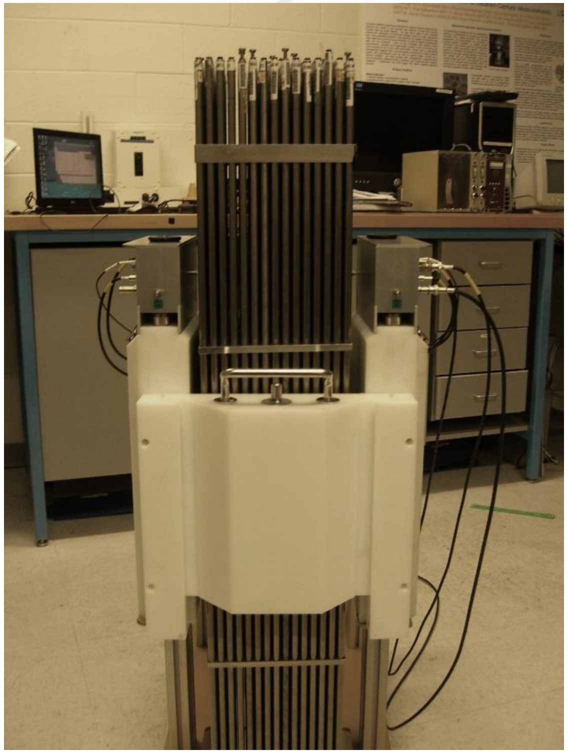
UNCLASSIFIED

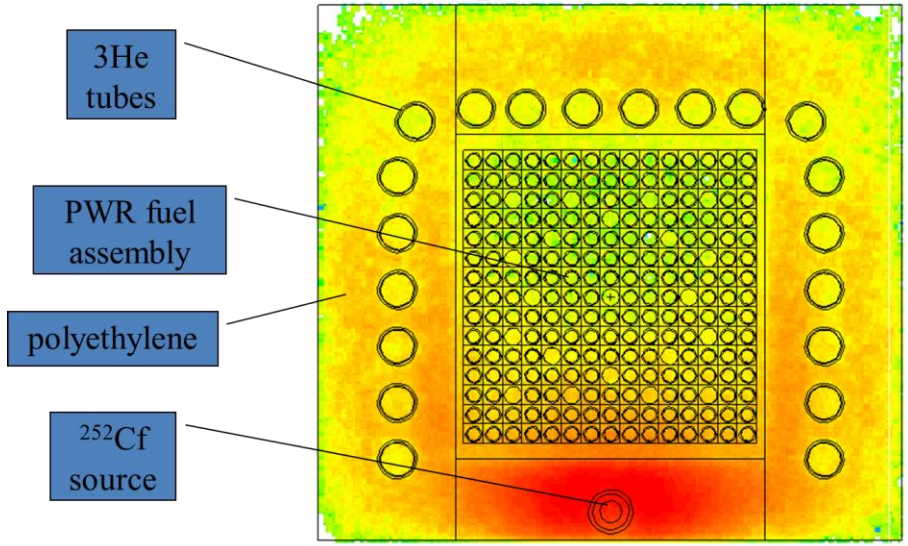
Sample calibration curve comparison



UNCLASSIFIED

Uranium Neutron Coincidence Collar (UNCL)





- Used for verification of fresh fuel assemblies (BWR and PWR)
- Response cross-calibrated to an absolute calibration curve
  - Different calibration curves for BWR and PWR

UNCLASSIFIED